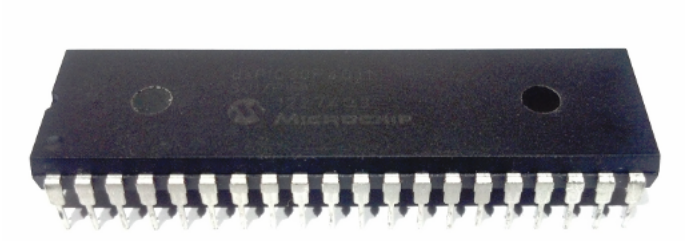
dsPIC

Elmer 166

An introduction to using the dsPIC



John J. McDonough, WB8RCR

dsPIC Elmer 166
An introduction to using the dsPIC
Edition 1

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The 16-bit Microchip PIC parts are very powerful and significantly easier to use than their 8-bit coounterparts. This book gives an introduction on how to use those parts, aimed specifically at the hobbyist.

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Preface

Overview

1.1. Overview of Microcontrollers

A microcontroller is a microprocessor intended for embedded[1] applications.

Microcontrollers differ from traditional microprocessors in a few key ways:

1. Microcontrollers generally are totally self-contained, requiring no external support other than power and sometimes a clock source.

2. Microcontrollers generally include non-volatile program memory so that the program need not be read from external media during startup. Most commonly, microcontrollers incorporate Flash memory for program storage.

3. Microcontrollers are generally Harvard Architecture processors rather than traditional von Neumann processors. The Harvard Architecture allows for different memory widths between the data and program memory, and the separate busses allow data and program instructions to be fetched during the same instruction cycle.

4. Embedded applications often require a high degree of detrminism. To support this, most microcontrollers execute all or most instructions in the same number of clock cycles. In contrast, microprocessors such as the Intel family may execute some instructions in just a few cycles, while others take dozens.

5. Microcontrollers tend to use most of their pins for I/O. In contrast, microprocessors tend to use their pins for data busses, multi-phase clocks, cache memory, and other, non-application purposes.

6. Microcontrollers frequently have a variety of available peripherals internal to the part. Serial ports, I2C interfces, analog to digital converters and the like are common. Microprocessors tend to have a few general putpose I/O pins, if that.

7. Micocontrollers typically have a number of power saving features, and often require very little power. Compare a typical dsPIC, requiring about 150 milliwatts at full speed with a typical PC microprocessor requiring 70 or more watts. And the dsPIC has features allowing it to reduce its power requirement to the nanowatt range for some applications. In many embedded applications the microcontroller current is less than the internal leakage current of the battery.

8. Microcontrollers tend to be inexpensive, ranging from around a quarter to perhaps ten dollars. Refer to *Appendix E, Microchip PIC Families* for examples. Microprocessor prices range from a few dollars to several hundreds of dollars. As of this writing, the suggested price for Intel's i7-3940XM is $1096.

[1] embedded system n. A combination of computer hardware and software, and perhaps additional mechanical or other parts, designed to perform a dedicated function. In some cases, embedded systems are part of a larger system or product, as in the case of an antilock braking system in a car.[*Barr*]

Figure 1.1. dsPIC Overview

Table 1.1. The dsPIC30F Family

	Minimum	Maximum	dsPIC30F4011
Program Memory	6K	144K	48K
Data Memory	256	8192	2048
EEPROM Memory	0	4096	1024
Pin Count	18	80	40
UART	1	2	2
SPI	1	2	1
I2C	1	2	1
CAN	0	2	1
Comparators	0	4	4
A/D Channels	6	18	9
Quadrature Encoder Inputs	0	1	1
Timers	2	5	5
Volume Price	$2.23	$7.25	$4.02
Quantity One Price	$3.09	$11.94	$5.70
Prices are from Microchip Direct for quantity one, from the Product Selector for volume prices			

1.2. The dsPIC30F4011

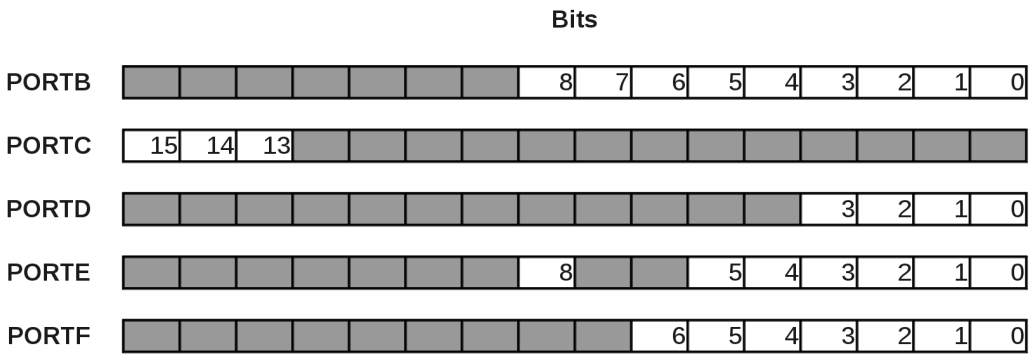

Figure 1.2. dsPIC30F4011 Ports

1.3. Building Programs

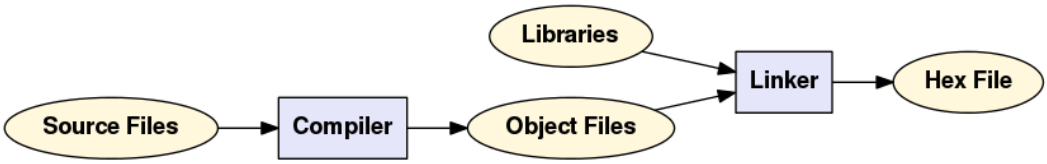

Figure 1.3. Program Building Process

First Program - Blink an LED

The first program will be the classic "flash an LED" program. This provides a simple look into programming the PIC without any unnecessary complexities. Well, maybe without too many complexities.

2.1. Creating the project

Everything done within **MPLAB-X** is done within the context of a project, so the first order of business is to set up a project.

Begin by launching **MPLAB-X**, either by double-clicking the desktop icon or selecting the **MPLAB-X IDE** from the menu.

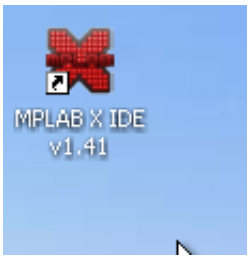

Figure 2.1. MPLAB-X desktop icon

The first time **MPLAB-X** is launched it will display the **MPLAB-X "Start Page"**. The start page has many interesting links worth pursuing at a later date.

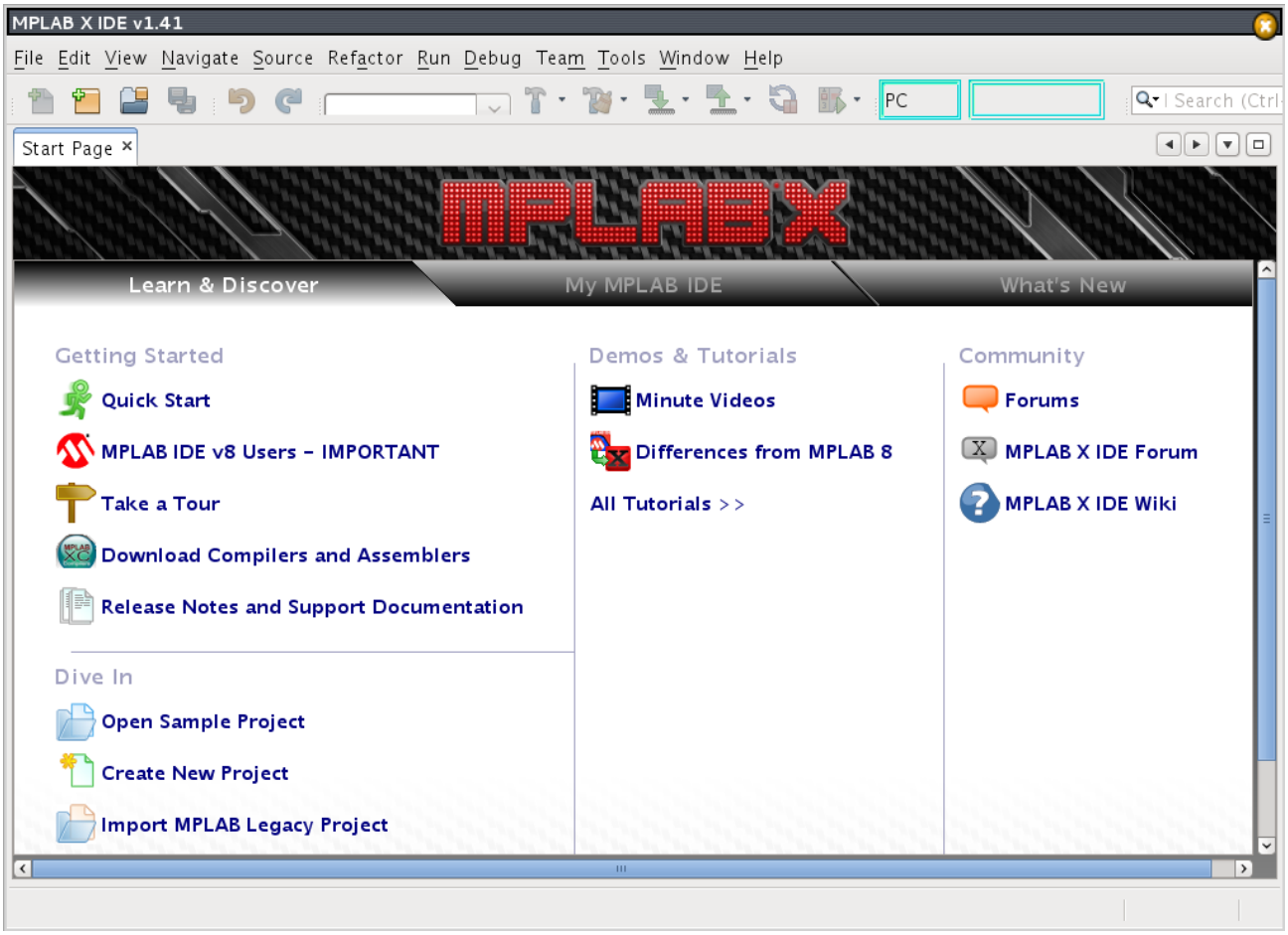

Figure 2.2. MPLAB-X Opening Screen

On successive launches, **MPLAB-X** will open with the same project that was opened when it was closed.

To create a new project, click the new project button at the left of the toolbar, or click **"Create New Project"** under **"Dive In"** on the start page.

Figure 2.3. New project button

This will launch the new project wizard.

The first panel chooses the overall type of project. Almost always the default selections of **"Microchip Embedded"** and **"Standalone Project"** are the desired choices.

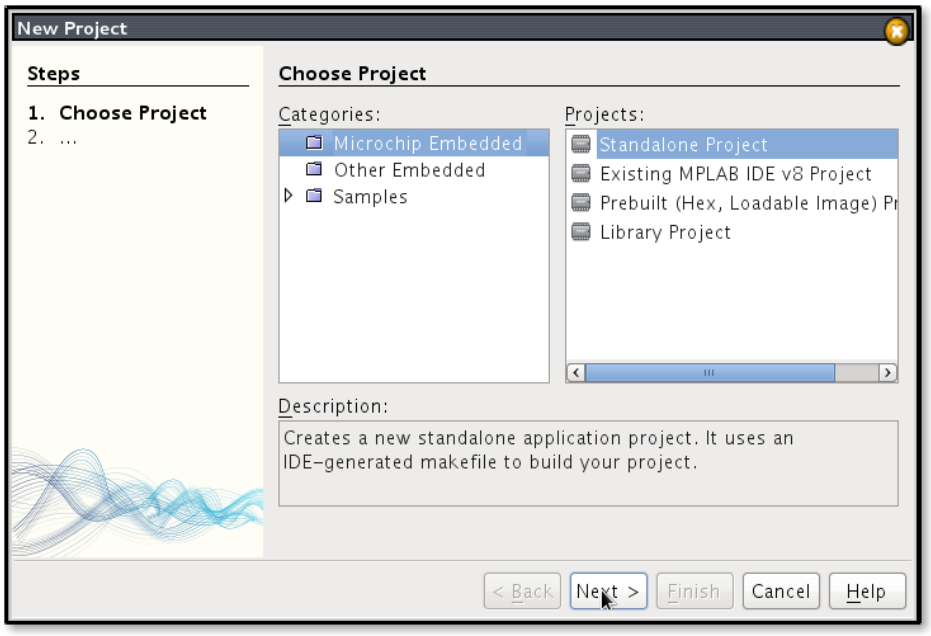

Figure 2.4. Select type of project

The next panel selects the specific processor. For this lesson, choose the **"16-bit DSCs (dsPIC30)"** Family and within that family, the **"dsPIC30F4011"** Device.

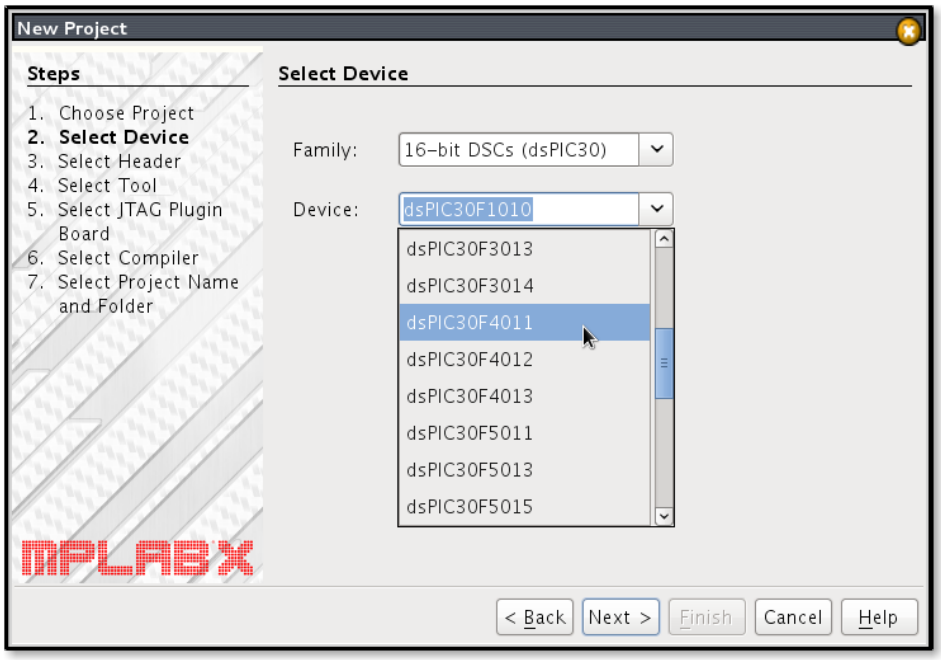

Figure 2.5. Select processor

The next selection is for the hardware programming or debugging tool. In this exercise, the simulator will be used to get a detailed view of what the program is doing before actually downloading it into the dsPIC, so select **"Simulator"**.

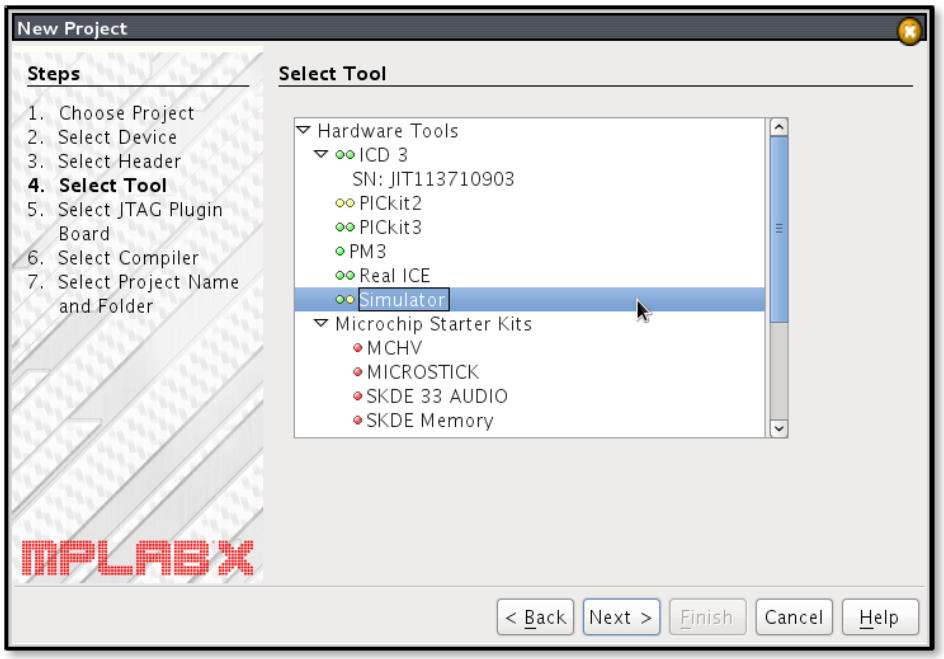

Figure 2.6. Select hardware tool

In the next panel, the compiler is selected. Choose **"XC16"**. (The version and path to the compiler may be different.)

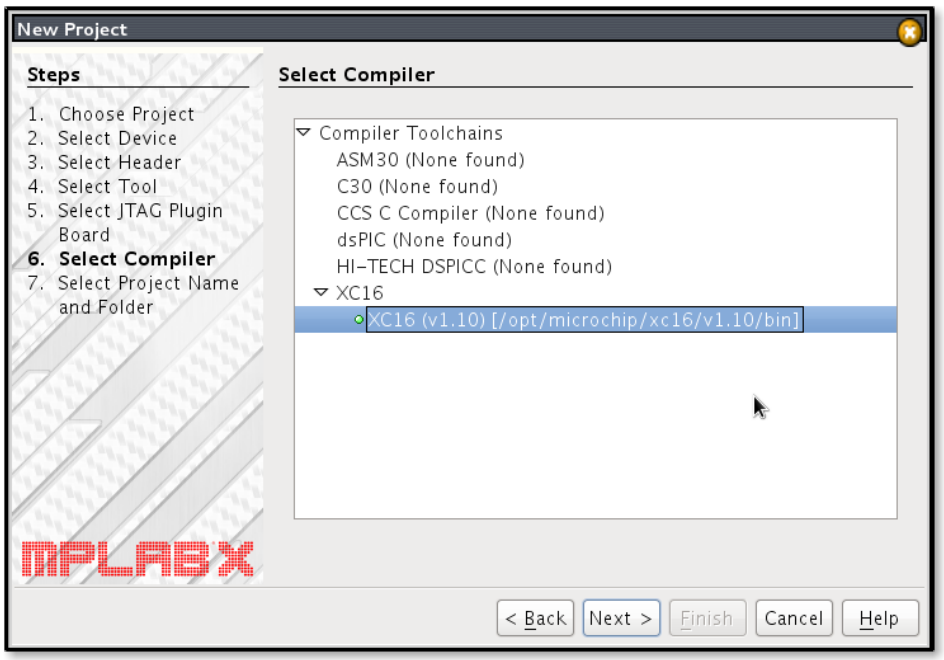

Figure 2.7. Select Compiler

In the final project wizard panel, enter a name for the project.

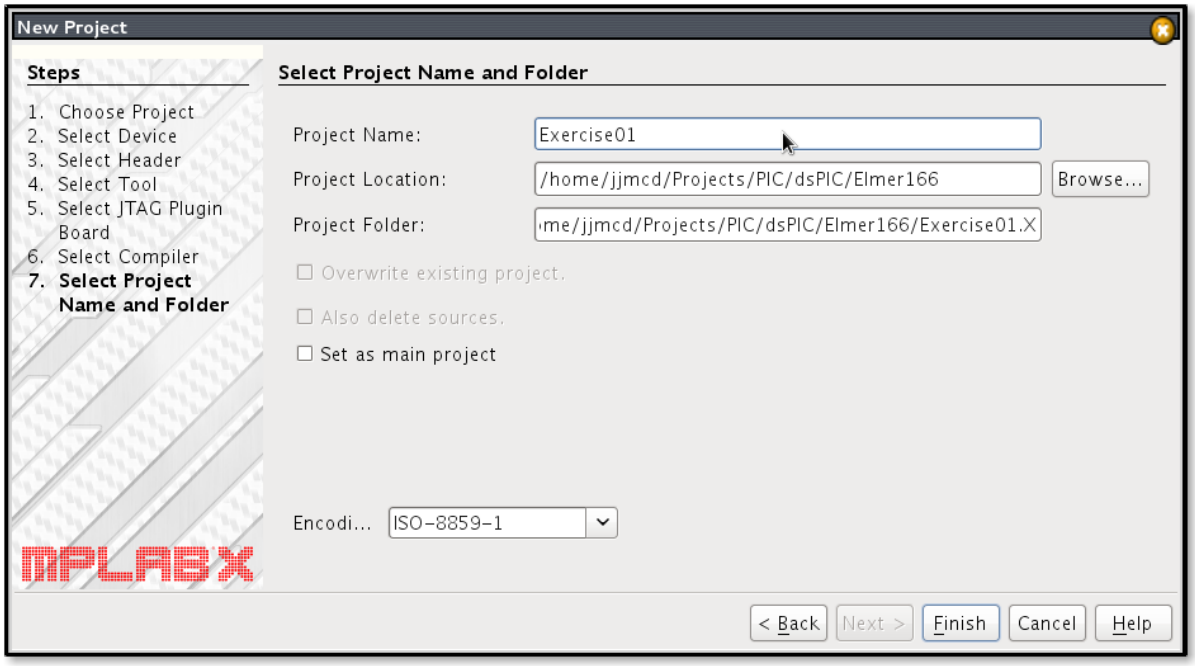

Figure 2.8. Assign project name

Two panes will open on the left of the main **MPLAB-X** window. The upper pane (labeled **Projects**) will list the various possible components of a project, while the lower will show an overall view of the project (called the "Dashboard"). In addition, a **"Tasks"** pane will open beneath the Start Page.

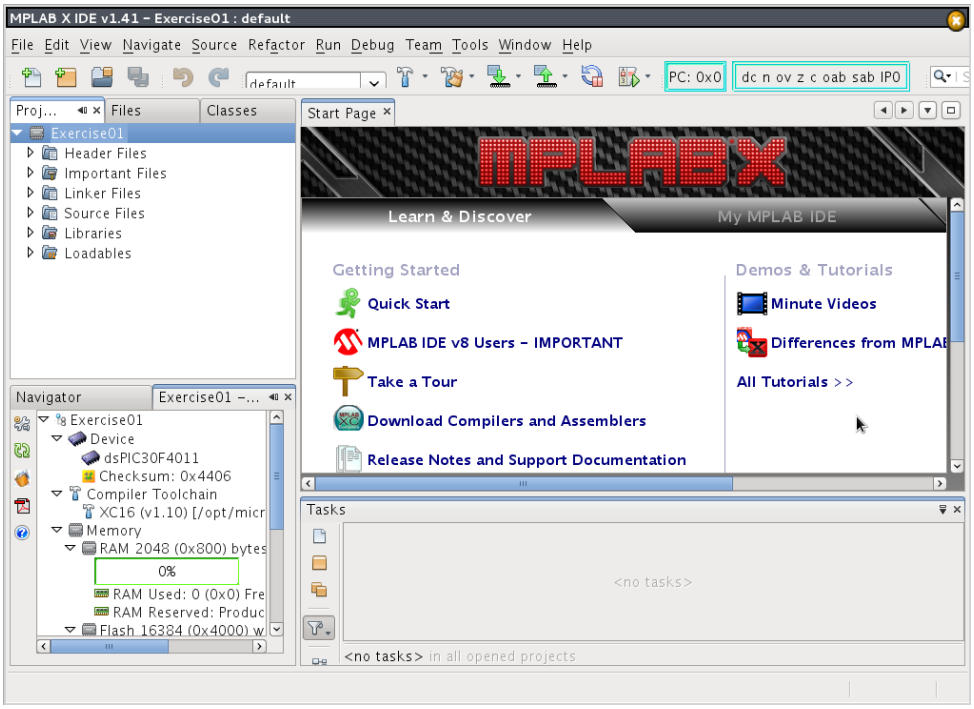

Figure 2.9. MPLAB-X Empty Project

Note the in **MPLAB-X** it is possible to place almost any pane in almost any position, and **MPLAB-X** remembers previous settings, so if the application had been used previously, the various panes may be in different locations or have different contents.

2.2. Editing and Compiling the Source

Once a project has been created, the next order of business is to create a file in the project to contain the code. Within the upper left (**Project**) pane, right-click on **"Source Files"**, roll over **"New"** and select **"Empty File ..."**.

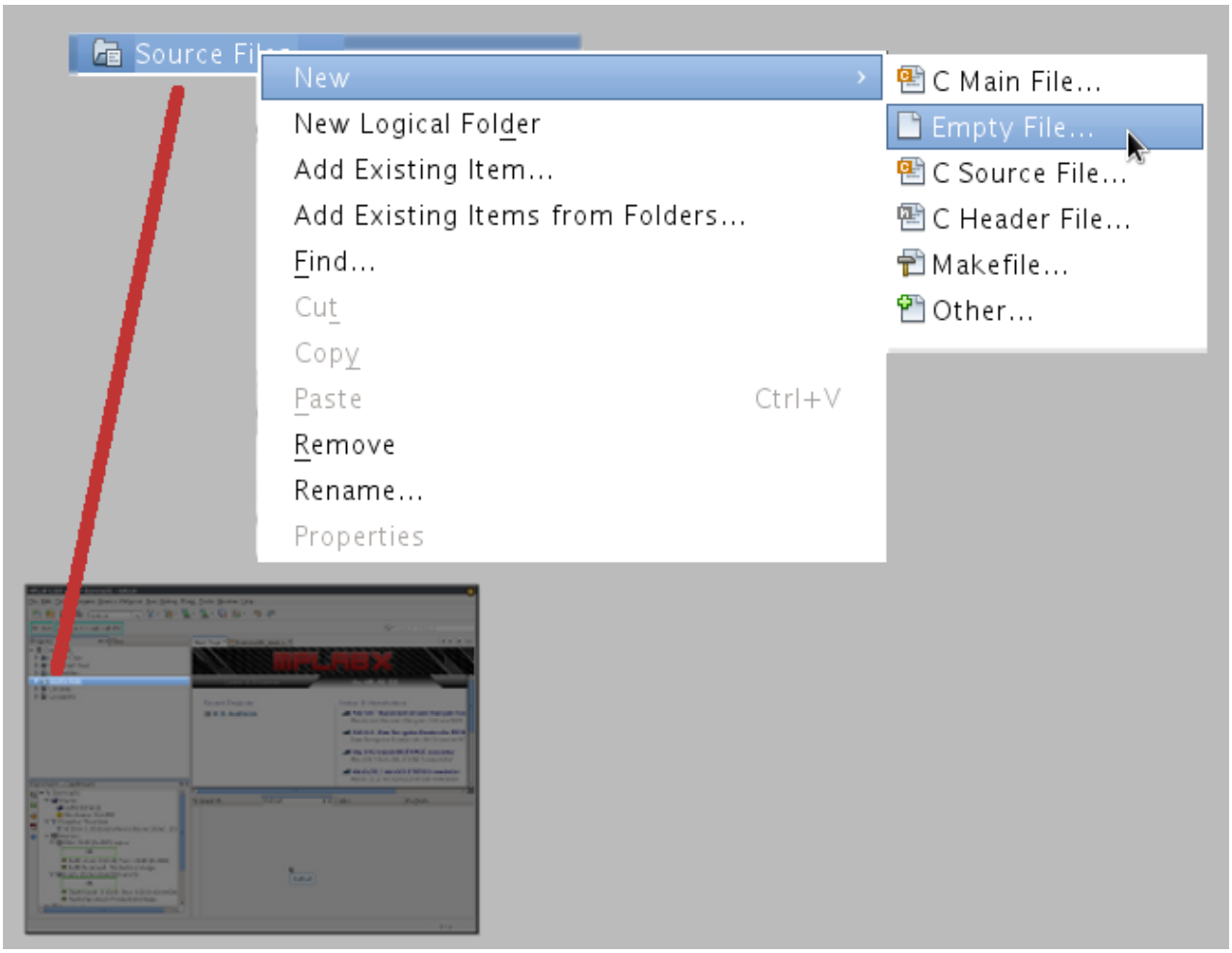

Figure 2.10. Add a new file to the project

A dialog will open allowing you to provide a name for the project. Be certain the filename you choose ends in **.c**. At this point it is worth considering your conventions for naming source files. It is the C tradition to name the mainline of a C program **main.c**. However, there will be a lot of **main.c**'s, so it could be preferable to name the mainline source the same as the name of the project. If you really like to type, you may prefer to combine both, as shown below.

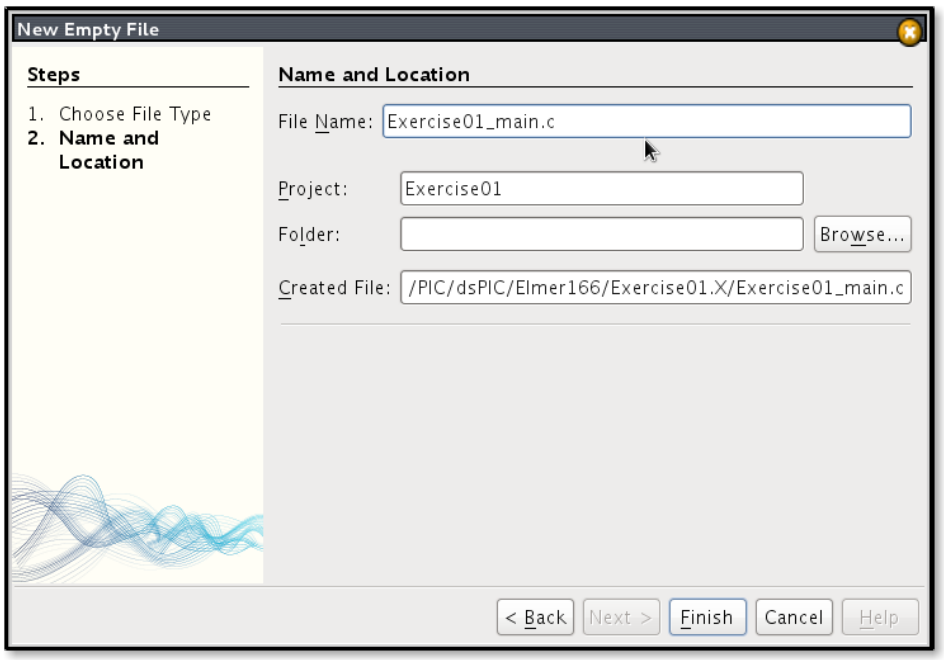

Figure 2.11. Name the new file

One problem with having very long names is that they take space in the project pane. If you have a lower resolution screen, you may prefer to leave as much space as possible for the rightmost pane, making your left panes smaller. it can be quite annoying if most of the filenames are hidden.

```
#include <xc.h>

int main()
{
    TRISDbits.TRISD1 = 0;

    while( 1 )
    {
        LATDbits.LATD1 = 0;
        LATDbits.LATD1 = 1;
    }
}
```

Refer to *Table F.1, "Include Files"* for a list of include file locations known to the compiler.

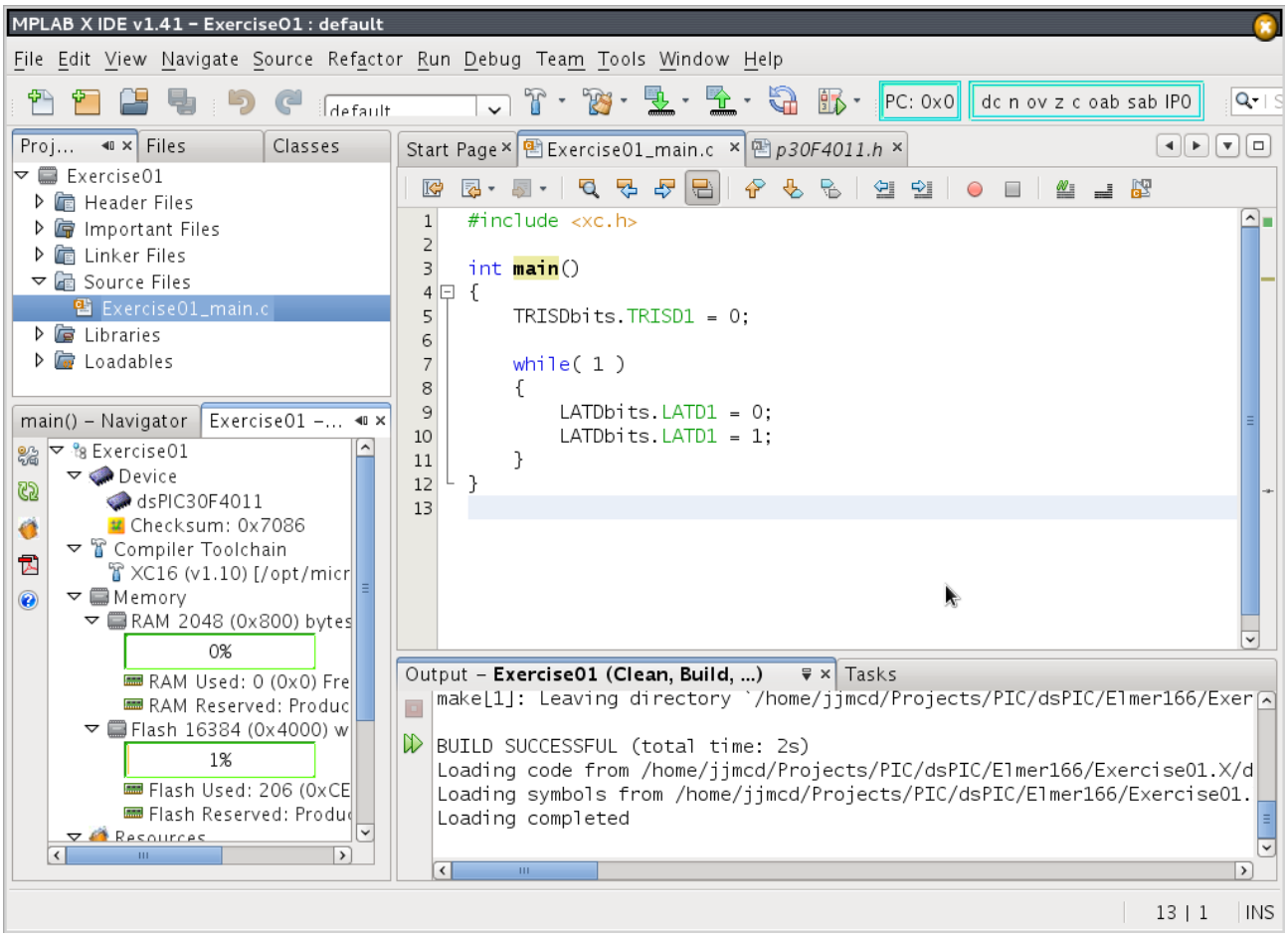

Figure 2.12. Add code

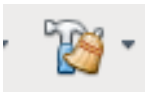

Figure 2.13. Compile button

2.3. Running the Simulator

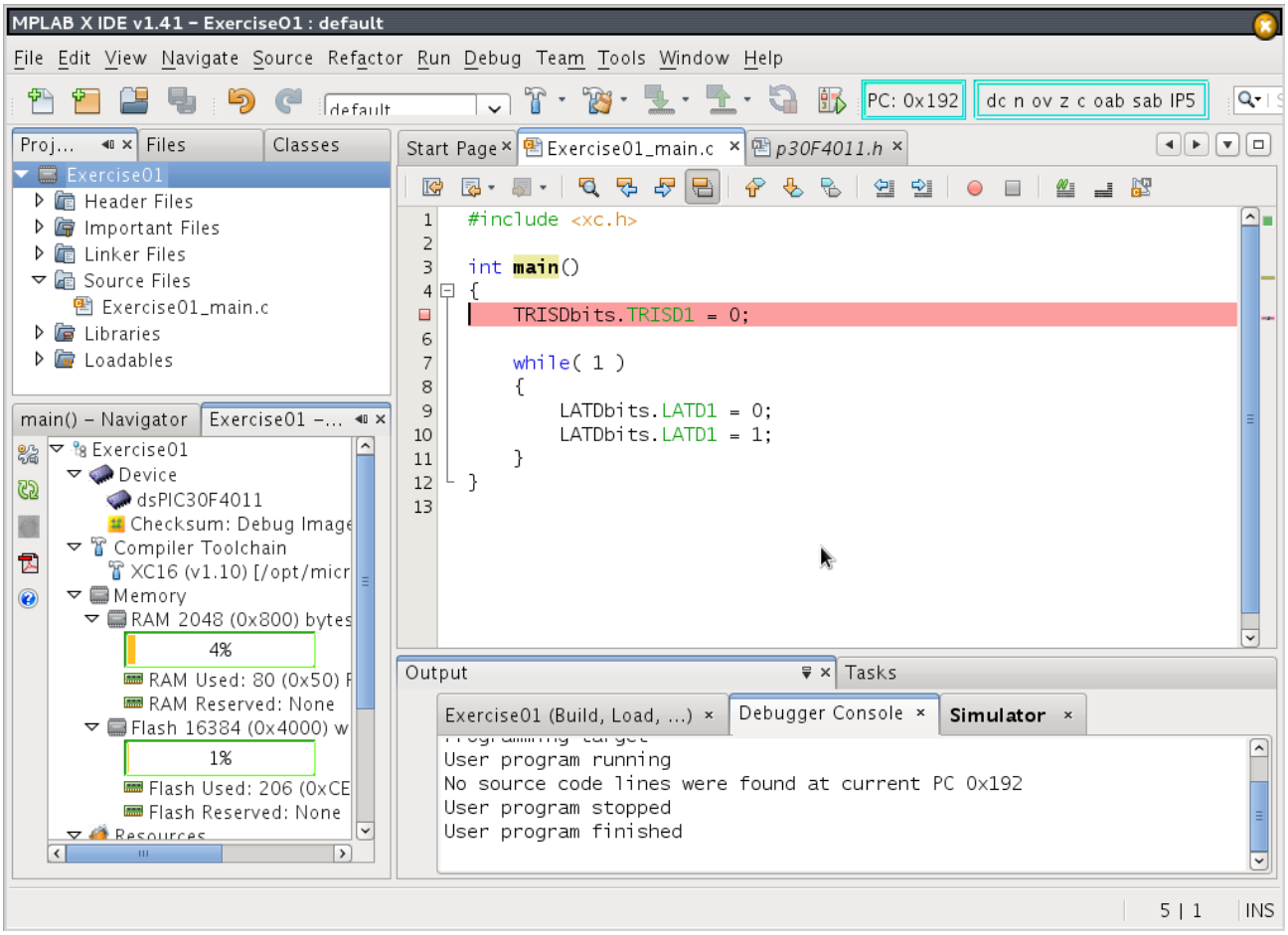

Figure 2.14. Set a breakpoint

Figure 2.15. Debug program button

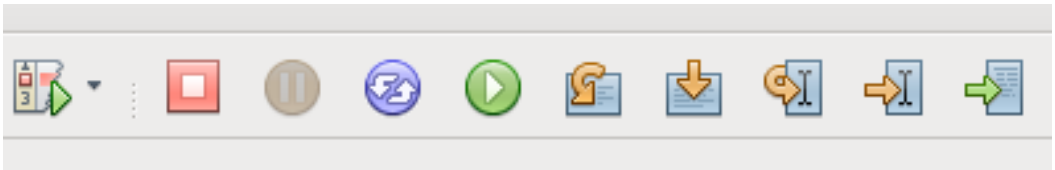

Figure 2.16. Debugging controls

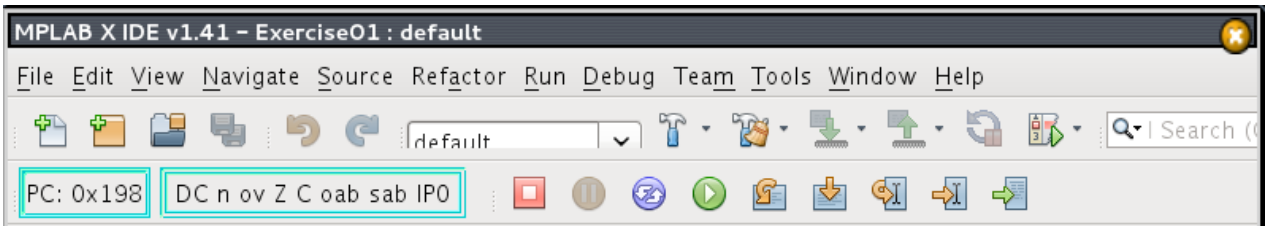
MPLAB X IDE v1.41 – Exercise01 : default
File Edit View Navigate Source Refactor Run Debug Team Tools Window Help
default
Search
PC: 0x198
DC n ov Z C oab sab IPO

Figure 2.17. Second toolbar row

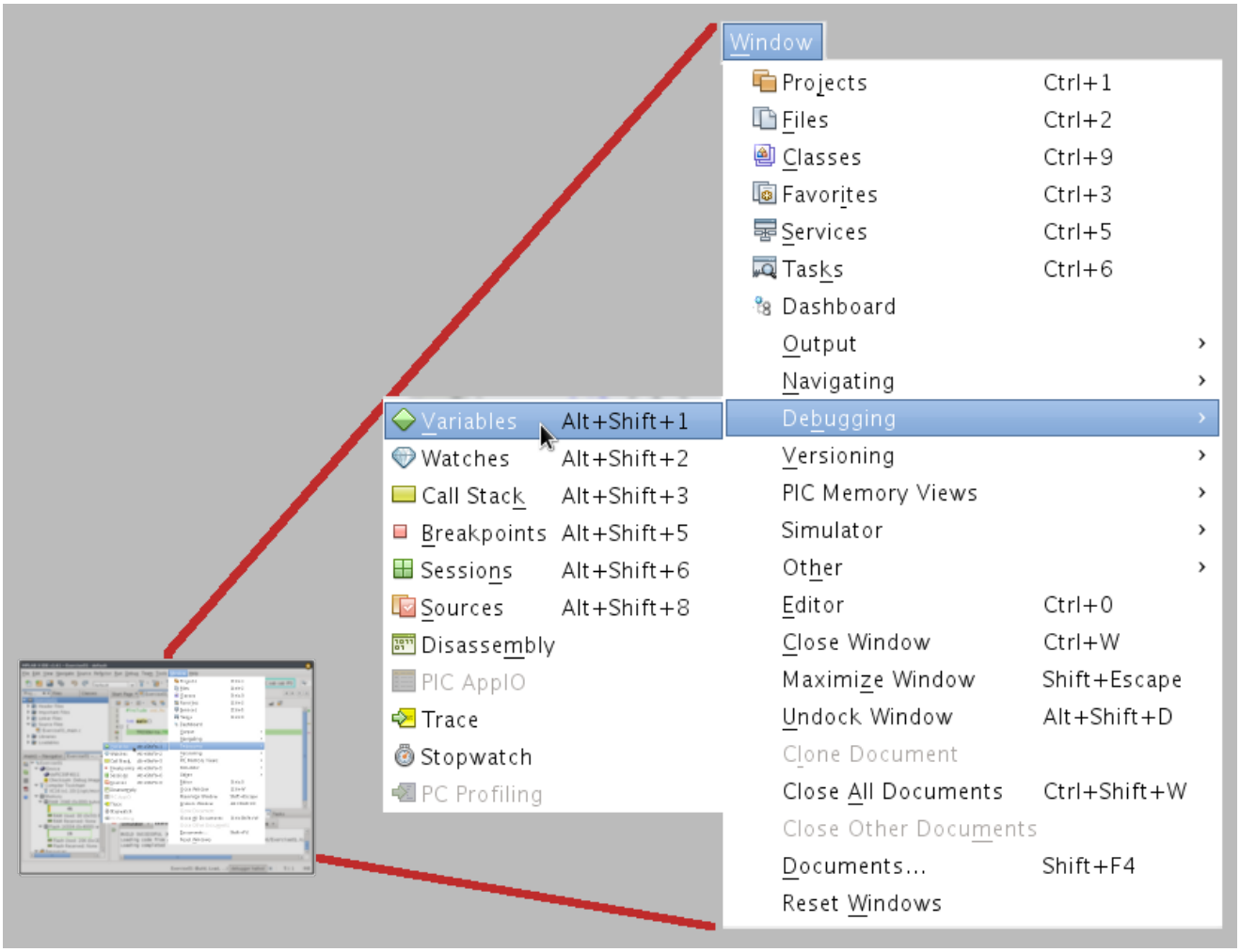

Figure 2.18. Open the variables window

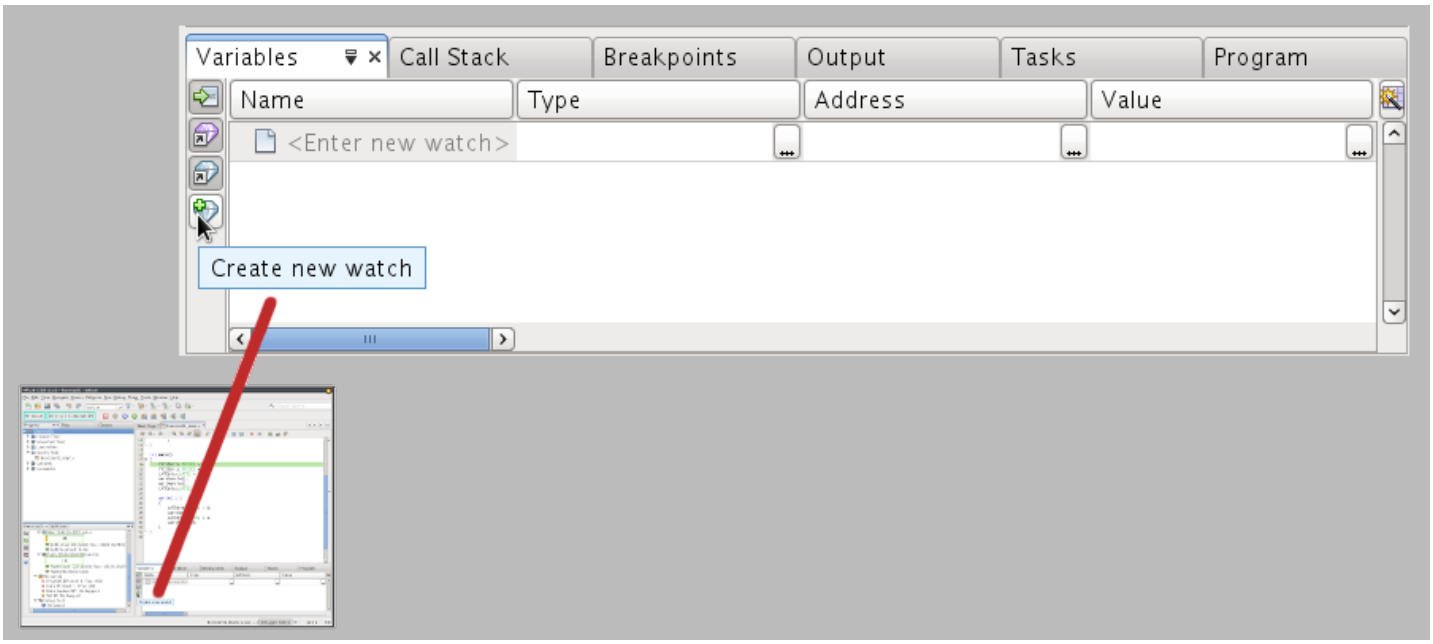

Figure 2.19. Create a watch expression

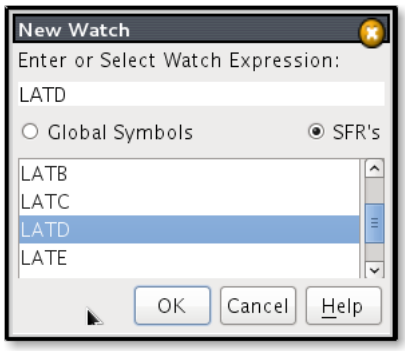

Figure 2.20. Select the variable to watch

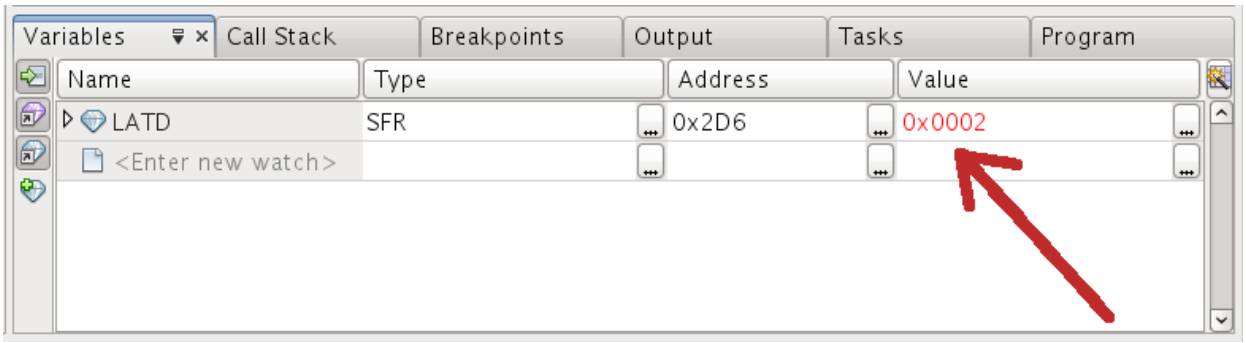

Figure 2.21. Observe the value change

2.4. Running the program in the dsPIC

Figure 2.22. Download program button

2.5. Debugging the program

2.6. Documenting the program

```
/* Exercise01_main.c - Blink an LED */

#include <xc.h>

int main()
{
    /* Set the LED pin to be an output */
    TRISDbits.TRISD1 = 0;

    /* Keep doing this a very long time */
    while( 1 )
    {
        /* Turn the LED on */
        LATDbits.LATD1 = 0;
        /* Turn the LED off */
        LATDbits.LATD1 = 1;
    }
}
```

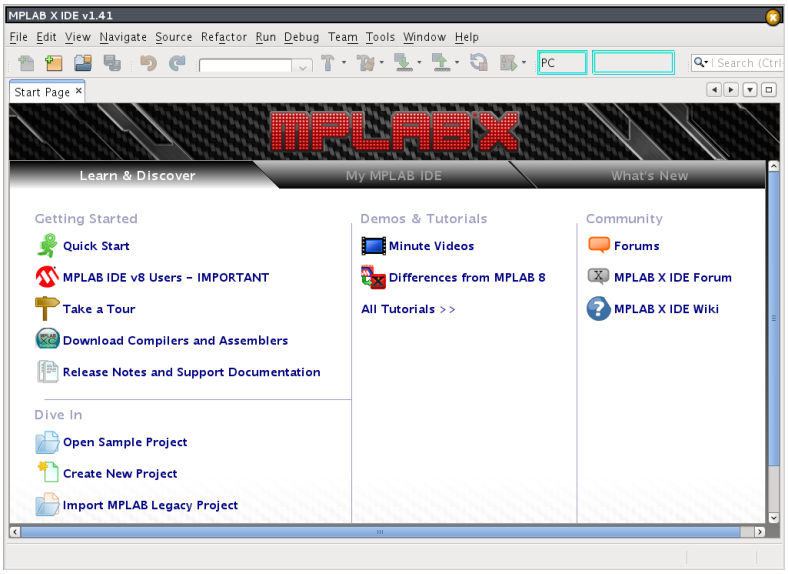

Figure 2.23. MPLAB-X

```
// Ex02.c - Blink an LED

#include <xc.h>                         (1)

int main (void)
{
  _TRISD3 = 0;                          (2)

  while (1)                             (3)
    {
      _LATD3 = 1;                       (4)
      _LATD3 = 0;                       (5)
    }
}
```

(1) Provides definitions for the dsPIC registers.

(2) Sets the pin connected to the LED to be an output.

(3) It will take some time before one becomes zero.

(4) Turns off the LED.

(4) Turns on the LED.

Configuration Registers

```
// Configuration fuses
_FOSC (XT)                              // 7.3728 xtal / 4 = 1.8432 MIPS
_FWDT (WDT_OFF)                         // Watchdog timer off
_FBORPOR (PWRT_16 & BORV27 & MCLR_EN)   // Brownout off, powerup 16ms
_FGS (GWRP_OFF & CODE_PROT_OFF)         // No code protection
```

Timers

```
// Set up timer
// 7.3728 MHz * 16xPLL /Fosc/4 / 256 prescaler / 57600 counter
// timer should fire twice per second.  Since the LED
// will toggle once per interrupt, the LED should come on
// once per second for a half second.
TMR2 = 0;             // Clear timer 2
PR2 = 57600;          // Timer 2 counter to 576000
T2CON = 0x8030;       // Fosc/4, 1:256 prescale, start TMR2
```

```
if ( IFS0bits.T2IF )
  {
    IFS0bits.T2IF = 0;
    LATD ^= 0x0002;
  }
```

Interrupts

```
  // Set up timer
  // 7.3728 MHz * 16xPLL /Fosc/4 / 256 prescaler / 57600 counter
  // timer should fire twice per second.  Since the LED
  // will toggle once per interrupt, the LED should come on
  // once per second for a half second.
  TMR2 = 0;             // Clear timer 2
  PR2 = 57600;          // Timer 2 counter to 576000
  T2CON = 0x8030;       // Fosc/4, 1:256 prescale, start TMR2
  IEC0bits.T2IE = 1;    // Enable timer interrupt
```

```
// Timer 2 interrupt routine - toggle the red (bottom) LED
// each time the interrupt occurs.
void __attribute__((__interrupt__, auto_psv)) _T2Interrupt( void )
{
    IFS0bits.T2IF = 0;      // Clear timer interrupt flag
                            // This is always the first order of
                            // business in an interrupt routine

    LATD ^= 0x0002;         // Toggle red LED
}
```

Liquid Crystal Displays

The I²C Device Routines

There are a large number of parts available using the Inter-Integrated Circuit, or I²C, communications protocol. I²C allows multiple devices to share a two line bus. Although communication with the devices may occur at any speed up to 3.4 Mb/s, common rates are 100 kb/s, 400 kb/s, 1 Mb/s, 1.7 Mb/s and 3.4 Mb/s. The clock is controlled by the bus master.

To allow multiple devices to share a single bus, each device has an address. The address may be a 7 bit or a 10 bit address, with devices supporting 7 bit addresses being far more common.

Routines for three different I²C devices are described.

- The MCP4726 Digital to Analog converter. The 4726 has an address range of 0x60 to 0x67 Not all addresses are equally available.
- The MCP23008 I/O Expander. The address of this device can be set by the user in the range of 0x20 to 0x27 by external pins.
- The MB85RC16V Ferroelectric Random Access Memory (FRAM). The FRAM uses addresses 0x50 through 0x57. The multiple addresses are necessary to address all of the memory within the device.

7.1. I²C Device Connections

I²C devices are wired in parallel, with pull-up resistors on the bus. The value of the resistor is determined by the speed desired (>2K for 5 volt systems, <20K depending on the bus capacitance[*PHI1*]). For higher speeds, the designer must take care to minimize the capacitance of the bus.

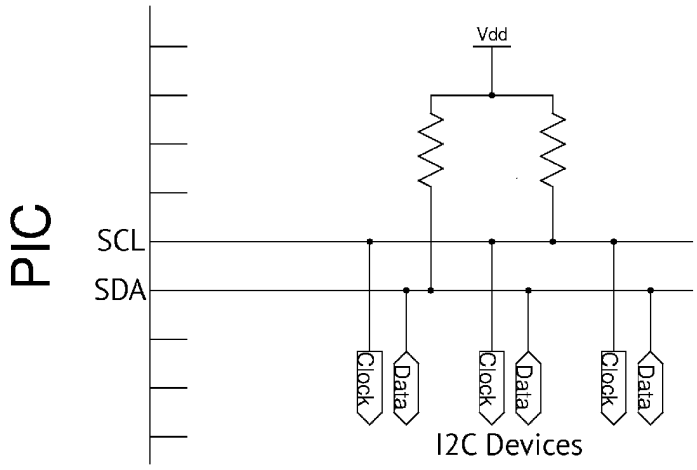

Figure 7.1. I2C Wiring

The included library **`i2c.a`** provides for writing a value to the DAC, reading and writing the I/O extender, and reading and writing the FRAM.

7.2. Using the MCP4726 DAC

Since the DAC is a relatively simple device, using the routine is quite straightforward. Although the MCP4726 includes a number of other features like RAM & EEPROM[*MCP6*], what the designer generally wants from a DAC is to output a specific voltage. The `MCP4726write()` function provides that capability.

In order to use any of the I²C routines, the user must include **`i2c.h`** and the header file for the particular device, in this case, **`MCP4726.h`**.

```
#include "../include/i2c.h"
#include "../include/MCP4726.h"
```

Before using any of the device routines, the I²C peripheral must be initialized. The function `InitI2C()` performs this initialization. The function sets the peripheral to master, establishes the baud rate, and sets reasonable defaults for a number of I²C parameters.

```
    InitI2C();
```

This need be done only once.

All that remains, then, is to write the data to the DAC. The `MCP4726write()` function takes two parameters, the address of the device and the value to be written. The MCP4726 is a 12-bit DAC, so the value is a 12 bit value.

```
    MCP4726write( 0x60, nValue );
```

Typically, the developer will want to write some fraction of "full scale" to the DAC, but it is possible that a specific voltage is desired. When presented with a value of 4095, the DAC will output the reference voltage, typically 5V. With a zero the device will output zero volts. Thus, if a 2048 is entered, the DAC will deliver 2.5 volts. If speed is not a concern, then, the code might look something like:

```
    /* Voltage fVolts from previous calculation */
    fDACvalue =  (fVolts / 5.0) * 4095.0;
    nDACvalue = (int)fDACvalue;
    MCP4726write( 0x60, nDACvalue );
```

or more directly:

```
    MCP4726write( DACADDR, (int)((fVolts / 5.0) * 4095.0) );
```

The floating point library is large and slow, so the programmer may prefer to stick with integers. In this case, it is important to avoid overflow in the calculations. While the DAC value may easily fit in an integer, an integer voltage would have low resolution, and multiplying millivolts by 4095 will often result in an integer overflow. The solution is to force the compiler to use long values for the intermediate calculations:

```
    /* Voltage nMillivolts from previous calculation */
    nDACvalue = (int)( (long)nMillivolts * 4095L / 5000L );
    MCP4726write( 0x60, nDACvalue );
```

7.3. Using the MCP23008 I/O Expander

The MCP23008 I/O Expander is a more complex device[*MCP5*]. It has eight I/O pins, each of which may be configured as an input or an output. This makes it useful when a large number of I/O devices are required and speed is not an issue (I^2C can only send thousands of commands a second, compared to millions of changes or tests per second possible directly to a port). Since the possible addresses allow for eight devices, a total of 64 digital I/O pins may be supported on a single I^2C bus.

The device has 11 registers that may be read or written. In most cases, only three of these registers are of interest; the `IODIR` register, comparable to the `TRIS` registers in the PIC, the `GPIO` register, comparable to the `PORT` registers in the PIC, and the `OLAT` register, comparable to the PIC `LAT` registers.

The remaining registers allow for setting weak pull-ups on inputs, setting default states for outputs, and allowing for interrupt on change.

The include file, **`MCP23008.h`** includes definitions for all the registers as well as function prototypes for the two provided functions, `MCP23008writeRegister()` and `MCP23008readRegister()`. As with all I^2C functions, **`i2c.h`** must also be included so that `InitI2C()` may be called:

```
#include "../include/i2c.h"
#include "../include/MCP23008.h"
```

If only input is required, calling `MCP23008readRegister()` fetches the current state of the pins:

```
    InitI2C();
    /* Get the current state of the I/O expander's pins */
    ucPortState = MCP23008readRegister( 0x20, MCP23008_GPIO );
```

The I/O extender defaults to input mode on power up.

For writing, the I/O direction register must first be set to make the desired pins be outputs. Like the PIC, a 0 bit sets the pin to be an output, so to make all pins outputs:

```
    MCP23008writeRegister( 0X20, MCP23008_IODIR, 0x00 );
```

Consider a case with a button on pin 1, and an LED on pin 4. To light the LED whenever the button was pressed. Our code might look something like:

```
    unsigned char ucPortValue;

    /* Initialize I2C and the MCP23008 */
    InitI2C();
    MCP23008writeRegister( 0X20, MCP23008_IODIR, 0xef );

    while ( 1 )
    {
        /* Get the state of the button */
        ucPortValue =  MCP23008readRegister( 0x20, MCP23008_GPIO );
        /* Is the button pressed? */
        if ( ucPortValue & 0x02 )
            /* Yes, turn on the LED */
            MCP23008writeRegister( 0X20, MCP23008_OLAT, 0x10 );
        else
            /* No, turn off the LED */
            MCP23008writeRegister( 0X20, MCP23008_OLAT, 0x00 );
    }
```

7.4. Using the MB85RC16V FRAM

The MB85RC16V Ferroelectric Random Access Memory[*FUJ1*] is a 2Kx8 non-volatile memory chip. It is useful in cases where the microcontroller does not include enough EEPROM for the application. Many of the 16-bit families do not include any EEPROM, so this can be useful in cases where other families are selected. The part can be used in both 3.3 and 5 volt designs.

The data retention for the MB85RC16V is only 10 years, so that is not an advantage over the dsPIC30F4011's EEPROM retention of 100 years. However, a single cell can be written 10^{10} times, considerably more than the EEPROM's one million writes, so the part might be considered for applications where many rewrites are expected.

The library contains two functions for using the FRAM, `MB85RC16VwriteByte()` and `MB85RC16VreadByte()`. In addition to the base address of the device (which must always be 0x50), the function takes an 11 bit address.

```
#include "../include/i2c.h"
#include "../include/MB85RC16V.h"
    .
    .
    .
    /* Initialize the I2C peripheral */
    InitI2C();

    /* Read a value from the FRAM */
    ucMemValue = MB85RC16VreadByte( 0x50, nAddress );

    /* Write a value to the FRAM */
    MB85RC16VwriteByte( 0x50, nAddress, ucMemValue );
```

The I²C Library

In addition to the device routines, the library includes a complete set of low level I2C routines for devices with seven bit I²C addresses. Almost all I²C devices may be supported with these routines.

Table 8.1. Low-level I²C functions

Operation	Function
Initialize the I²C peripheral	void InitI2C(void)
Start an I²C transaction	unsigned int StartI2C(void)
Restart an I²C transaction	unsigned int RestartI2C(void)
Terminate an I²C transaction	unsigned int StopI2C(void)
Write a byte to an I²C device	void WriteI2C(unsigned char)
Read a byte from an I²C device	unsigned char getI2C(void)
Check that the I²C bus is idle	void IdleI2C(void)
Send an acknowledgement to an I²C device	void AckI2C(void)
Set a non-acknowledge (NAK) to an I²C device	void NotAckI2C(void)
Test the acknowledge status of the I²C bus	unsigned int ACKstatusI2C(void)

8.1. The I²C Transaction

Operations on the I²C bus are handled as **`transactions`**[*PHI1*]. The transaction must be started, then operations may take place, and then the transaction must be stopped before another transaction may take place.

In the case of a microcontroller communicating with a set of peripheral ICs, the microcontroller is the bus master, and is responsible for starting and stopping transactions. The slave sends an acknowledge bit at the end of each byte sent by the master. In the case of the dsPIC, handling the acknowledge bit is dealt with by the hardware.

8.2. The I²C Control Byte

The first byte sent in any transaction is the control byte. The control byte contains the target device address in the high seven bits. The low bit is cleared if the master intends to write data to the slave, and set if the master expects the slave to send data. However, a set read/write bit may only be sent following an I²C restart.

Thus, a function to communicate with a device will calculate the control byte by shifting the address one bit to the left clearing the low bit:

```
    ucControlByte = ucDeviceAddress<<1;
```

8.3. Sending data to an I²C device

Thus to send data to a device the sequence is: starting the transaction, sending the control byte, sending the data, and stopping the transaction. Once again, it is important to study the device datasheet. Many devices expect to receive multiple bytes of data in each transaction.

As an example, consider the MCP4726 DAC[*MCP6*]. This is a 12 bit DAC. Since only 8 bits may be sent to the device at a time, the data must be broken up into two transmissions, the first sending the high four bits and the second, the lower eight:

```
    /* Write condition is a zero bit so the control byte is formed
     * merely by shifting the address left one bit */
    ucControlByte = ucDevice<<1;

    /* Break value into two bytes */
    ucByteH = uValue >> 8;
    ucByteL = uValue & 0xff;

    StartI2C();         /* Start I2C transaction            */
    WriteI2C(ucControlByte); /* Address of MCP4726 | write  */
    WriteI2C(ucByteH);  /* high 4 bits of value             */
    WriteI2C(ucByteL);  /* Low 8 bits of value              */
    StopI2C();          /* Stop the transaction             */
```

8.4. Reading data from an I²C device

Reading data is a bit more complex. The master must send the control byte as usual, and often, must send the slave some indication of what information is needed. The master must then restart the transaction and send the control byte, this time with the read bit set. The master (dsPIC) may then read the data from the device. The data must then be acknowledged or not acknowledged by the master before stopping the transaction. In many cases, the default is to not acknowledge (NAK) the data, because an acknowledge (ACK) is a signal to the device to send more data! Again, it is critically important to become familiar with the device datasheet.

Consider the MCP23008 I/O extender[*MCP5*]. The master must start the transaction, send the control byte, then send the register whose contents are desired. Then the transaction is restarted, the data fetched from the slave, and a NAK sent. Finally the transaction may be stopped. Should the master have sent an ACK, the 23008 would then send the contents of the *next* register:

```
    /* Write condition is a zero bit so the control byte is formed
     * merely by shifting the address left one bit */
    ucControlByte = ucDevice<<1;

    StartI2C();                 /* Start I2C transaction            */
    WriteI2C( ucControlByte );  /* Send bus Address                 */
    WriteI2C( ucRegister );     /* Address of desired register      */
    RestartI2C();               /* Restart so can send read         */
    WriteI2C( ucControlByte+1 );/* Send bus address with read bit   */
    ucResult = getI2C();        /* Get answer from MCP23008         */
    NotAckI2C();                /* NAK result to stop answers       */
    StopI2C();                  /* Send stop on bus                 */
```

Building Libraries

Analog Inputs

```
  // Initialize ADC
  /* set port configuration here */
  ADPCFGbits.PCFG8 = 0; // ensure AN8/RB8 is analog
  /* set channel scanning here, auto sampling and convert,
     with default read-format mode */
  ADCON1 = 0x00E4;
  /* No channel scan for CH0+, Use MUX A,
     SMPI = 1 per interrupt, Vref = AVdd/AVss */
  ADCON2 = 0x0000;
  /* Set Samples and bit conversion time */
  ADCON3 = 0x1f3f; //(as slow as possible)
  /* set channel scanning here for AN8 */
  ADCSSLbits.CSSL8 = 1;
  /* channel select A3 */
  ADCHSbits.CH0SA3 = 1;
  /* reset ADC interrupt flag */
  IFS0bits.ADIF = 0;
  /* enable ADC interrupts */
  IEC0bits.ADIE = 1;
  /* turn on ADC module */
  ADCON1bits.ADON = 1;
```

```
//! ADC Interrupt Service Routine

/*!
 * Whenever an analog value is available, thie routine will:
 * \li Clear the interrupt flag
 * \li Grab the analog value and store it in potValue
 * \li Increment analogRead
 *
 */
void __attribute__ ((__interrupt__, auto_psv))
_ADCInterrupt (void)
{
  IFS0bits.ADIF = 0; // Clear A/D interrupt flag
  potValue = ADCBUF0; // Save the potentiometer value
  analogRead++; // Remember it has been read
}
```

Reading Switches

Pulse Width Modulation

```
// Set up timer 2 for PWM
TMR2 = 0;               // Clear timer 2
PR2 = 1000;             // Timer 2 counter to 1000
T2CON = 0x8010;         // Fosc/4, 1:4 prescale, start TMR2

// Set up PWM on OC2 (RD1)
OC2RS = 1024;           // PWM 2 duty cycle
OC2R = 0;               //
OC2CON = 0x6;           // Set OC2 to PWM mode, timer 2
```

```
  // Loop through 360 degrees
  for ( theta=0.0; theta<TWOPI; theta += 0.05 )
    {
        // Set the brightness of the LED based on the sine
        // of the angle.
        OC2RS = (int)(512.0-512.0*sin(theta+PIOVER4));
        // Slow it down
        for ( i=0; i<50000; i++ )
            ;
    }
```

Serial Output

Serial Input

Unusual Devices

Appendix A. Installing MPLAB-X

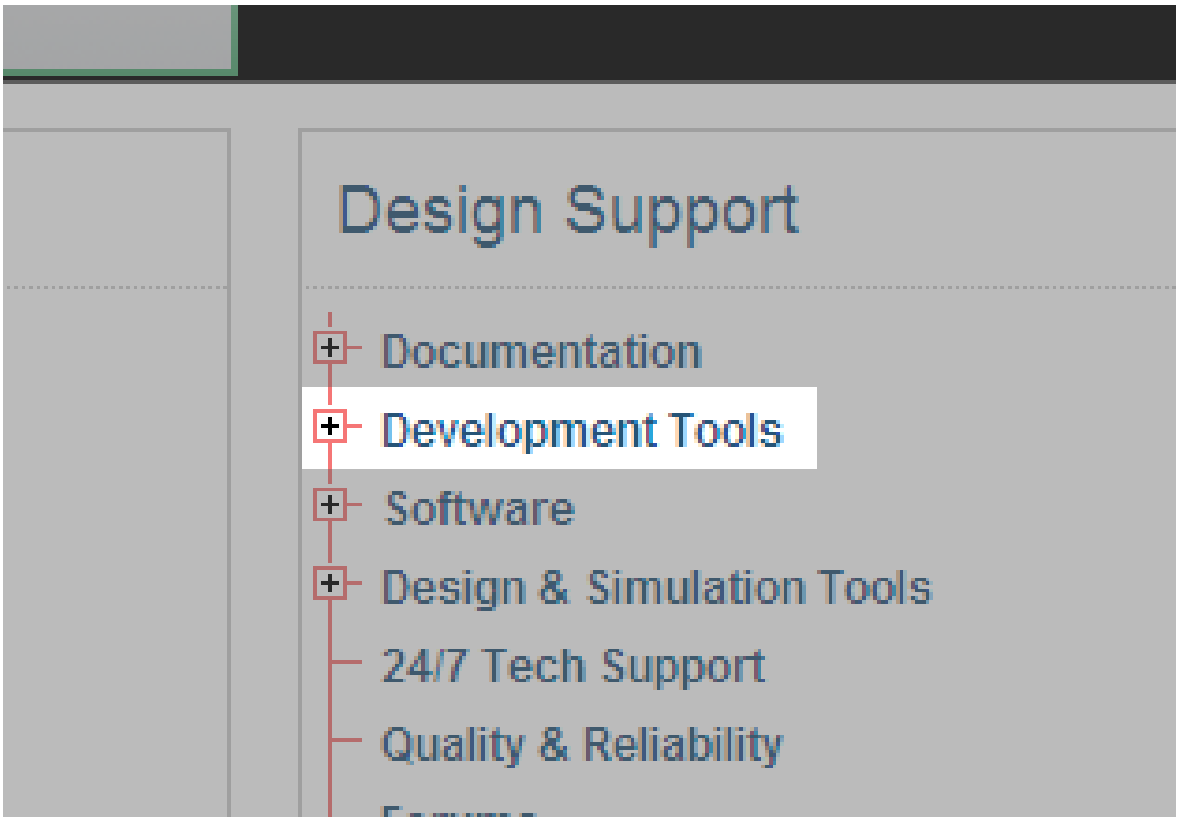

Figure A.1. Locate the Development Tools

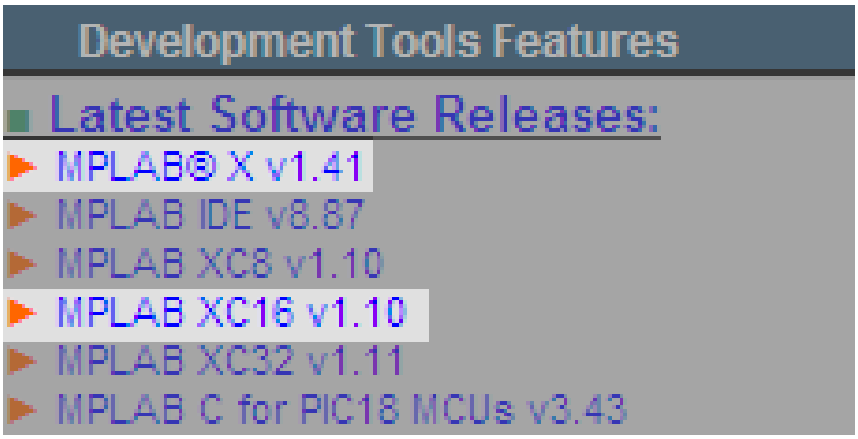

Figure A.2. Select Tools to Download

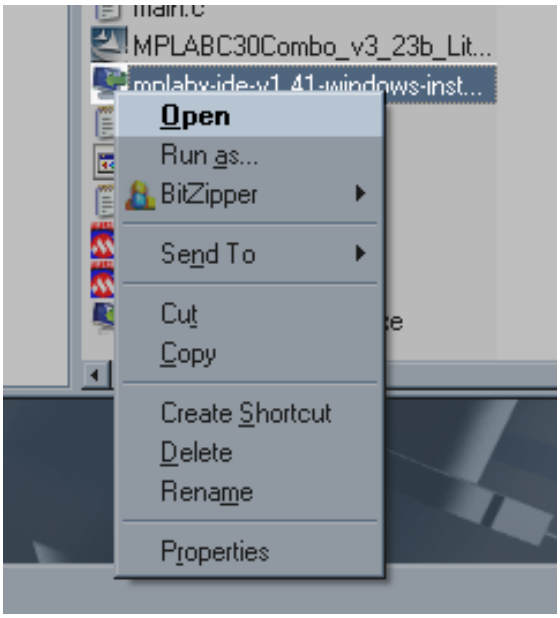

Figure A.3. Open Downloaded Installer

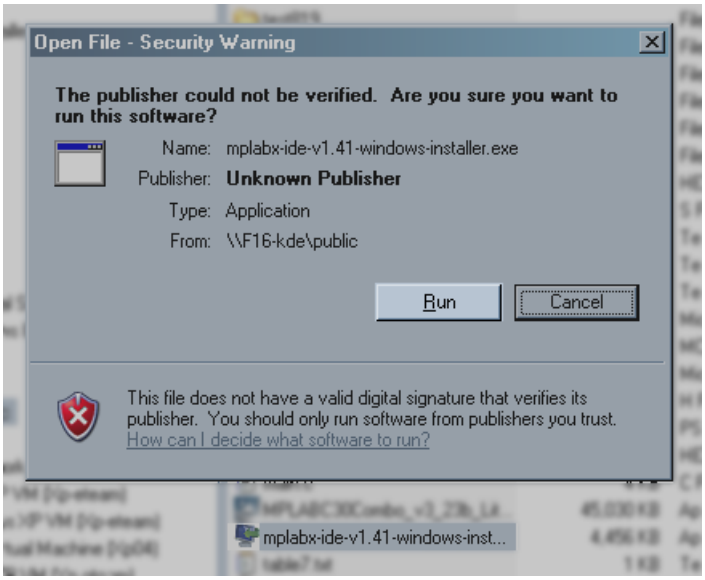
Open File - Security Warning
The publisher could not be verified. Are you sure you want to run this software?
Name: mplabx-ide-v1.41-windows-installer.exe
Publisher: Unknown Publisher
Type: Application
From: \\F16-kde\public
Run
Cancel
This file does not have a valid digital signature that verifies its publisher. You should only run software from publishers you trust.
How can I decide what software to run?
mplabx-ide-v1.41-windows-inst...

Figure A.4. Allow it to run

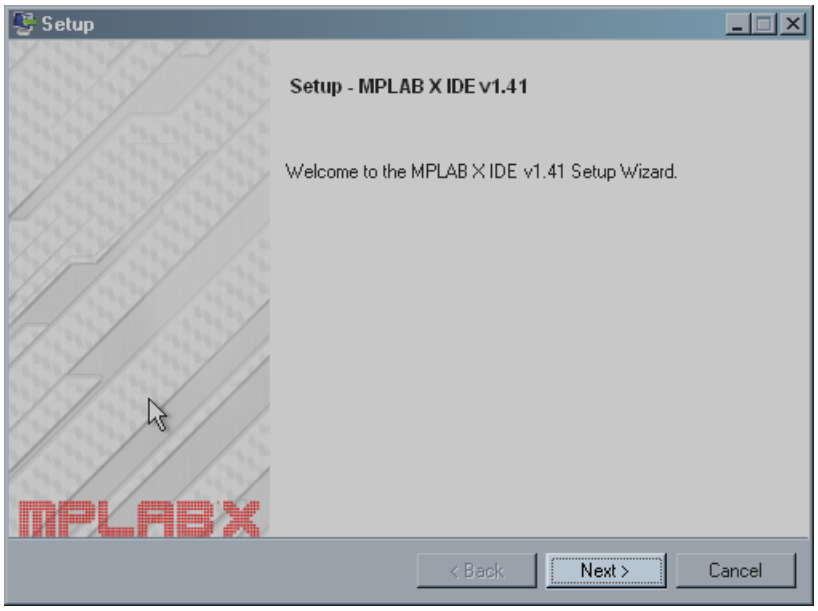

Figure A.5. Install Wizard

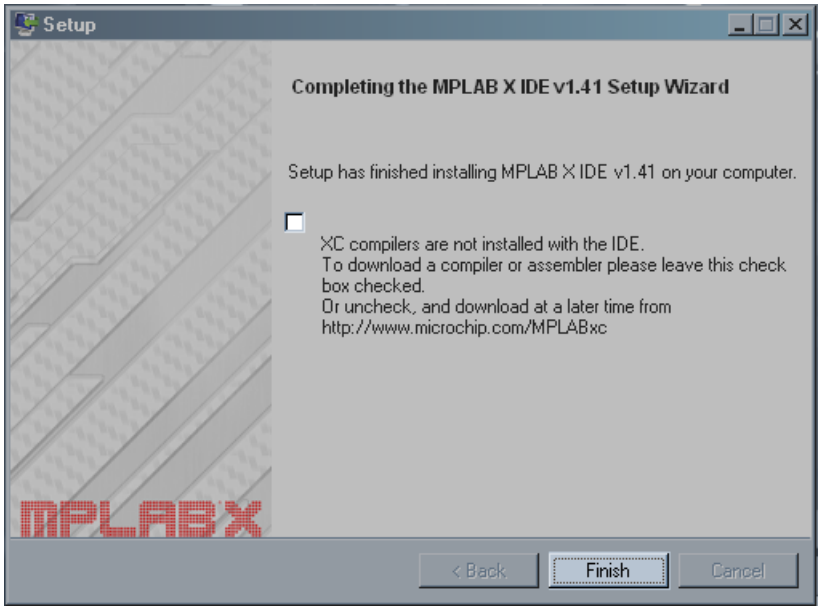
Setup
Completing the MPLAB X IDE v1.41 Setup Wizard
Setup has finished installing MPLAB X IDE v1.41 on your computer.
XC compilers are not installed with the IDE.
To download a compiler or assembler please leave this check box checked.
Or uncheck, and download at a later time from http://www.microchip.com/MPLABxc
MPLABX
< Back
Finish
Cancel

Figure A.6. XC Already Downloaded

Appendix B. Setting up a project in MPLAB-X

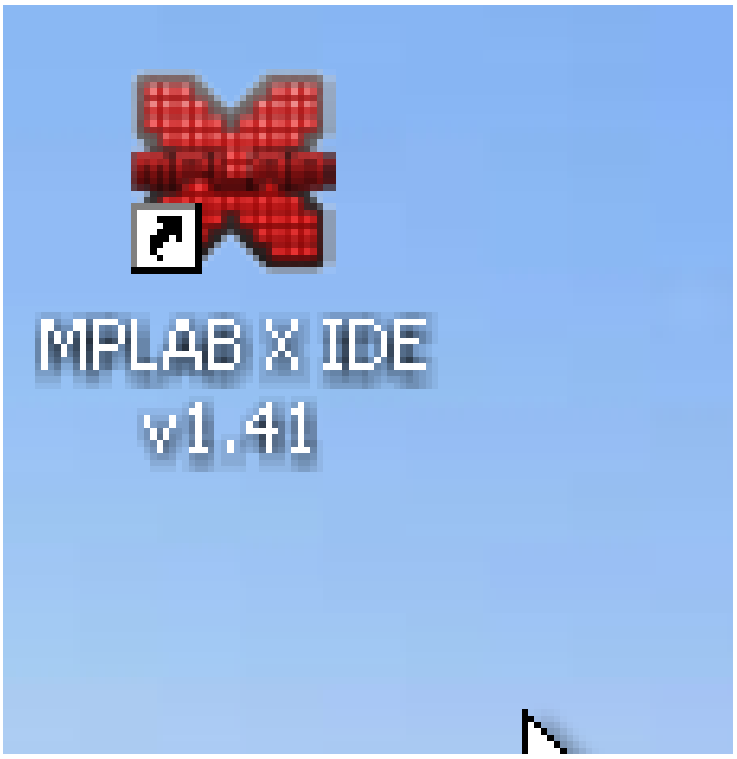

Figure B.1. MPLAB-X Desktop Icon

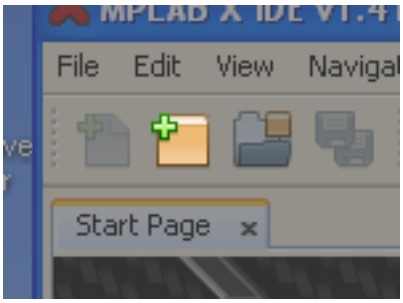

Figure B.2. New Project Button

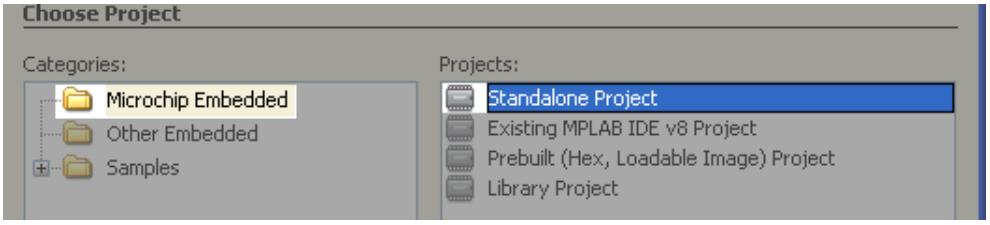

Figure B.3. MPLAB-X Project Type

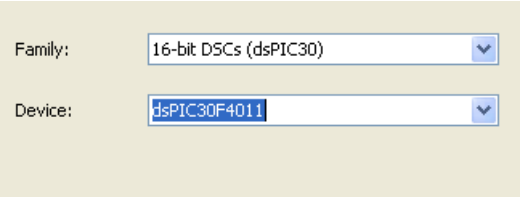

Figure B.4. Selecting the Processor

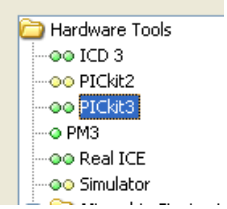

Figure B.5. Select Programmer/Debugger

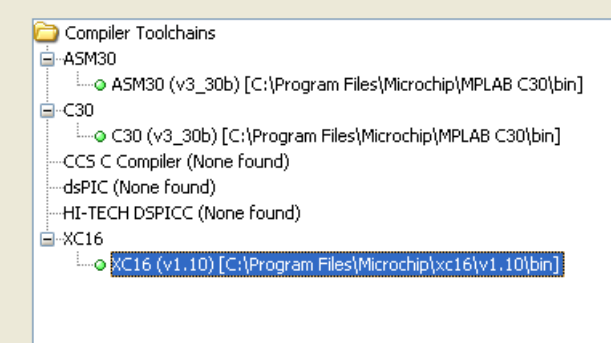

Figure B.6. Selecting the Toolchain

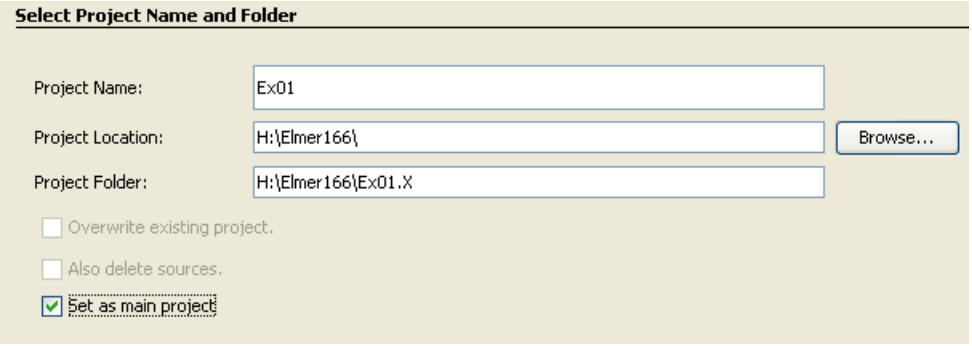

Figure B.7. Name the Project

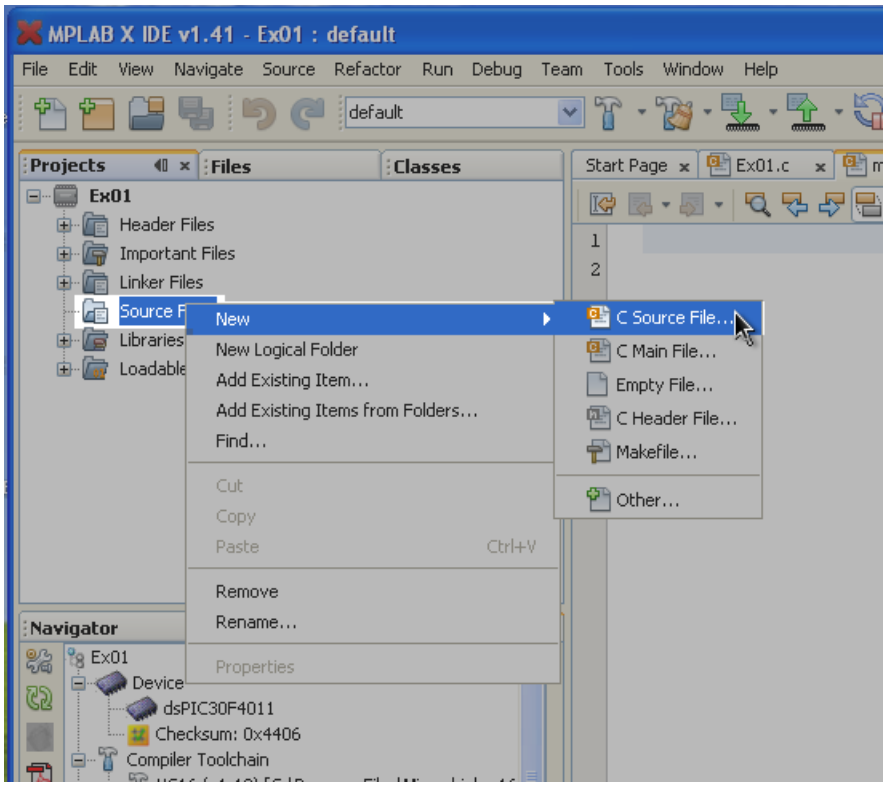

Figure B.8. Create a Source File

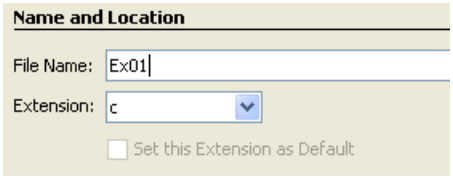

Figure B.9. Name the Source File

Appendix C. The C Language

C.1. Introduction

This appendix will not turn you into an expert C programmer, nor is it even a decent tutorial. it will, however, give you a little bit to get started with.

C is actually quite a simple language. There are only a handful of keywords and precious few rules. Indeed, this lack of rules does tend to be difficult for folks coming from older languages such as Basic or FORTRAN.

In this course, we won't be making use of a lot of elaborate code. Embedded [1] applications by their nature tend to be simple. Even someone unfamiliar with programming should have little problem following the code.

There are a few things about C that take a little getting used to. The following few paragraphs outline the most obvious:

All whitespace is created equal

In C, a space, tab and newline are all called whitespace. Any combination of these characters is also whitespace. Thus, a tab is the same as a space, as is three newlines followed by a space, or fourteen tabs. They are all equivalent to a single space. One result is that the end of a line has nothing whatsoever to do with the end of a statement. Statements may cross line boundaries with impunity. The exception is a string literal. String literals are not allowed to cross line boundaries. However, there are ways of writing newlines in literal strings.

Everything is case sensitive

Identifiers, keywords, anything C cares about is case sensitive. Thus, **`A`** has nothing to do with **`a`**, **`if`** is a keyword while **`IF`** is not.

C will not try to out-guess you

In many languages, the compiler will prevent you from doing really stupid things. Not so in C. If you wrote it, the compiler assumes you meant it, no matter how silly it may be. One fairly obvious place where people can go wrong is in arrays. If you declare an array of, say, ten integers, and then access the hundredth element of that array, C will assume that is exactly what you meant, and merrily return whatever is in memory where the hundredth element of that array would have been, had it actually been

[1] The Embedded Systems Glossary[*Barr*] provides the following definition for an embedded system, focusing largely on the application: "embedded system n. A combination of computer hardware and software, and perhaps additional mechanical or other parts, designed to perform a dedicated function. In some cases, embedded systems are part of a larger system or product, as in the case of an antilock braking system in a car."
Wikipedia[*WP1*] focuses more on the hardware: "An embedded system is a computer system designed for specific control functions within a larger system, often with real-time computing constraints. It is embedded as part of a complete device often including hardware and mechanical parts. By contrast, a general-purpose computer, such as a personal computer (PC), is designed to be flexible and to meet a wide range of end-user needs. Embedded systems control many devices in common use today."

that long. Of course, this can have very unfortunate side effects. But C has great faith that you knew what you were doing when you wrote that.

C.2. Identifiers

Variables and functions in C are assigned names called identifiers. ANSI C sets some minimum requirements for identifiers, but also allows some implementation flexibility. As a general rule, **XC16** makes maximum use of that flexibility.

An identifier is a sequence of letters and/or digits which must begin with a letter. The underbar (_) character counts as a letter.[*KandR*] Identifiers may be of any length, and all characters are significant. [*MCP1*] (The ANSI standard requires at least the first 31 characters be significant). Identifiers are case sensitive.

C.3. Types, Operators and Expressions

C.3.1. Scalar types

There are two general categories of values within C; integer and floating point. Within those categories are a number of different types. What those types actually mean is somewhat implementation dependent. For example, **`int`** is an integer of the natural size for the target processor. **`long`** is an integer the same size as **`int`** or longer, **`short`** the same size as **`int`** or shorter.

For **XC16** the following are the integer types:[*MCP1*]

Table C.1. Integer Types

Type	Bits	Min	Max
`char`	8	-128	127
`signed char`	8	-128	127
`unsigned char`	8	0	255
`short`	16	-32768	32767
`signed short`	16	-32768	32767
`unsigned short`	16	0	65536
`int`	16	-32768	32767
`signed int`	16	-32768	32767
`unsigned int`	16	0	65535
`long`	32	-2147483648	2147483647
`signed long`	32	-2147483648	2147483647
`unsigned long`	32	0	4294967296
`long long`	64	-9223372036854775808	9223372036854775807
`signed long long`	64	-9223372036854775808	9223372036854775807

Type	Bits	Min	Max
unsigned long long	64	0	18446744073709551615

The following are the floating point types:

Table C.2. Floating Point Types

Type	Bits	Exponent Min	Exponent Max
float	32	-126	127
double	32	-126	127
long double	64	-1022	1023

A number containing no decimal and not beginning with a zero is assumed to be a decimal constant of the type **int**. In many contexts, however, the compiler may recognize that some other type was intended such as **unsigned** or **long**.

A number beginning with a **0** is taken as an octal constant. In this case the digits **8** and **9** are not permitted. A number beginning with **0x** is taken as a hexadecimal constant. In this case the additional characters **a A b B c C d D e E f F** are permitted.

A binary constant may be specified as a string of **1** and **0** characters preceded by **0b**.

A constant may be specified as **long** by suffixing it with **l** or **L**. A constant may be specified as **unsigned** by suffixing it with **u** or **U**.

Constants may also be represented as their ASCII equivalents when surrounded by single quotes. For example, **0x31**, **49** and **'1'** represent the same value.

There are a number of special strings called escape sequences that may be used to represent special characters in ASCII constants:

- **\0** - 0, the NULL character
- **\a** - 7, the bell character
- **\b** - 8, the backspace character (not the same as the backspace key)
- **\t** - 9, the tab character
- **\n** - 10, the newline character
- **\v** - 11, the vertical tab character
- **\f** - 12, the formfeed character
- **\r** - 13, the carriage return character
- **\0** followed by octal digits - the octal value of a character
- **\0x** followed by hex digits - the hexadecimal value of a character

C.3.2. Array and Pointer types

Pointer types are very important in C, perhaps more important than in many languages. A pointer is a variable that contains the address of some object.

C also allows the specification of arrays of any type, even other aggregate types, including arrays. An issue that can be challenging at first is that the name of an array is a pointer to an array.

A pointer is specified by prefixing the name with an **`*`** in the declaration. Thus, **`int *n;`** specifies a pointer, **`n`**, which points to an integer.

A pointer declaration does not allocate memory

The declaration of a pointer only allocates the pointer. It does not allocate any space for the thing that might be pointed *to*.

An array is declared by suffixing the name with the ordinality surrounded by square brackets (**`[]`**). Thus, **`unsigned long g[10];`** would declare an array of 10 elements of **`unsigned long`** named **`g`** and allocate the necessary memory. Array elements are numbered starting at zero, thus, in the above example, valid elements are numbered zero through nine.

Since a pointer and an array name are the same, and may be used interchangably, incrementing a pointer or an array name increments it by the size of the thing pointed to. The same holds for any arithmetic. Thus, in the code below:

```
int array[10];
int *pointer;
int a;

pointer = array;
a = array[5];
pointer = pointer + 5;
a = *pointer;
```

`a = array[5];` and **`a = *pointer;`** have the same effect.

Similarly, an "element" of a pointer may be specified. For example:

```
int array[10];
int *pointer;
int a;

pointer = array;
a = array[5];
a = pointer[5];
```

Character strings in C are simply arrays of **`char`**. The compiler treats these arrays no differently than other arrays, except that there is a convenient way of expressing a string literal; it is simply a string of characters surrounded by double quotes.

By convention, a character string is terminated by a NULL character. The compiler does not enforce this, except that the compiler does provide the terminating NULL for a literal string. Most library routines, however, count on this, so it is generally important to be sure the terminating null is preserved when strings are manipulated.

When a character string is declared, it is important to include space to allow for the terminating NULL. Thus **`char myString[10];`** provides space for a nine character string plus the terminating NULL.

C.3.3. Structure and Union types

```
struct
  {
    int PointID;
    double Temperature;
    double ScalingFactor;
    double Offset;
    char Name[32];
  } TemperaturePoint[10];
```

```
union
  {
    long a;
    struct
      {
        int b1;
        int b2;
    } b;
  } longintunion;
```

C.4. Control Flow

C.5. Functions and Program Structure

C.6. The C preprocessor

C.7. dsPIC-specific identifiers

Appendix D. The dsPIC-EL Board

Appendix E. Microchip PIC Families

	MIPS	Flash	RAM	Pins	Data Bits	Core Bits	Low	High
PIC10	4	0.9K	64	6	8	12	$0.30	$0.39
PIC12	8	7K	256	14	8	12	$0.41	$1.12
PIC16	12	28K	2048	80	8	14	$0.39	$4.12
PIC18	16	128K	4096	100	8	16	$1.18	$8.44
PIC24F	16	256K	98304	100	16	24	$1.00	$5.60
dsPIC30F	30	144K	8192	80	16	24	$2.23	$7.25
PIC24H	40	256K	16384	100	16	24	$2.09	$5.08
dsPIC33F	50	256K	30720	100	16	24	$1.57	$5.67
PIC24E	70	512K	53248	144	16	24	$1.86	$6.99
dsPIC33E	70	512K	53248	144	16	24	$1.86	$6.99
PIC32	80	512K	131072	100	32	128	$1.51	$6.62

Figure E.1. PIC Families

Appendix F. Compiler Support Locations

The following directories are all relative to the compiler install directory which is typically something like (some directory)**/microchip/xc16/**(version)**/**. The following tables show only locations relevant to the dsPIC30F family of processors. There are additional directories for other processors. Your installation may use **** instead of **/**.

Table F.1. Include Files

Directory	Contents
include	Contains header files associated with the standard (non-PIC specific) C libraries
support/dsPIC30F	Contains definitions for the registers specific to the various models of dsPIC30F chips
support/peripheral_30F_24H_33F	Contains detailed definitions of the various peripherals
support/generic	Contains definitions applicable to all 16 bit PICs

Table F.2. Linker Script Files

Directory	Contents
support/gld/dsPIC30F	Linker script files for each of the dsPIC30F processors

Table F.3. Library Files

Directory	Contents
lib	Libraries common to all 16-bit microcontrollers and DSCs
lib/dsPIC30F	Libraries specific to the dsPIC30F family of Digital Signal Controllers

Appendix G. Revision History

Revision 0-3 **Sun Jan 20 2013** **John McDonough** ***wb8rcr@arrl.net***

Earl corrections

Revision 0-2 **Wed Jan 9 2013** **John McDonough** ***wb8rcr@arrl.net***

Add chapters on I2C

Revision 0-1 **Fri Oct 26 2012** **John McDonough** ***wb8rcr@arrl.net***

Initial prose

Revision 0-0 **Tue Sep 4 2012** **John McDonough** ***wb8rcr@arrl.net***

Initial creation of book by publican

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